International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 09 | Sep 2021 www.irjet.net p-ISSN: 2395-0072

An Investigation on Boiler Chimney Against Fouling to Enhance the Efficiency of Boiler

Satish Prakash Thakare(1), Dr. Khizar Ahmed Pathan(2)

(1)Department of Mechanical Engineering, Trinity College of Engineering and Research, Pune, Maharashtra, India.
(2)Professor Department of Mechanical Engineering, Trinity College of Engineering and Research, Pune, Maharashtra, India.

---***---

Abstract - *There are many reasons for the heat loss in the boiler, such as Hot flue gas is discharged into the atmosphere through the chimney, the discharge of hot waste water and the heat transfer from the hot surface. In this research work, the chimney was originally designed for a 15-ton/hour, 16-bar boiler. The problem with the chimney is that the largest number of carbon particles are formed in this chimney structure. To overcome the problem, the chimney is redesigned to reduce the accumulation of scale that affects the efficiency of the boiler. It is specially developed for boiler chimneys. At the end of the design, a hatch was provided in the chimney. The purpose of this project is to reduce the cross-sectional area of this special section to increase the flue gas flow.*

Key Words*: Boiler, Chimney, Redesign*

1. INTRODUCTION

A chimney is a structure that allows hot flue gas or smoke from a boiler, stove, oven, or chimney to be discharged into the atmosphere. The joint is usually vertical or, if possible, in order to ensure a smooth gas flow by drawing air into the combustion in the so-called chimney or chimney effect. The height of the chimney affects its ability to discharge flue gas outdoors. In addition, the diffusion of pollutants in high altitude areas can reduce their impact on the environment.

Fouling is the accumulation of unwanted materials on hard surfaces at the expense of functionality. Inanimate matter (inorganic or organic). Fouling is usually distinguished from other surface-growth phenomena, in that it occurs on a surface of a component, system or plant performing a defined useful function, and that the fouling process impedes or interferes with this function shown in fig. 1.

Fig -1: Fouling in chimney

The boilers used in industry works on very high temperature & pressure. Some flue gases form in the boiler which required exhausting in atmosphere through chimney. During this process some fouling are formed on the boiler chimney surface. After some period, fouling will become considerable which affects life of chimney.

Mostafa M. Awad (2011) studied the various aspects related to fouling of heat exchanger including various aspects such as types of fouling, fouling processes and mechanisms, time dependency of fouling, cost of fouling beard by various organization which leads to corrosion and reduction in economy, Parameters affecting fouling, fouling measurements and monitoring, Performance data analysis, fouling mathematical models, its design and various cleaning and controlling methodologies.Moni Kuntal Bora and S. kafle (2014) has focused on collaborative study of boilers fouling. Boiler efficiency may play an important role in the coming years. Industries all over the world are experience increasingly fierce competition and automated production. The cost of running such a system is expected to be very high. This document explains more clearly how to deal with this issue. Rahul Dev Gupta *et at.* (2011) point out that the resulting ideas have been submitted to a boiler house efficiency study conducted in a large boiler house in a pulp and paper mill. The low efficiency of the boiler is due to various heat losses, such as the loss of unburned coal in the waste, the loss of dry flue gas, the loss of moisture in the fuel, the loss of radiation, the loss of sewage, and the loss of hydrogen combustion. Various heat losses were analyzed, and some implementation suggestions were provided to the plant management personnel, there by improving the efficiency of the boiler. The management followed five important recommendations and found that the boiler efficiency has improved significantly. Only five recommendations were implemented in this work, which produced a net result. Increase the overall efficiency of the boiler by 2%. In addition, it has been observed that careful handling of the boiler can greatly improve the energy efficiency of the boiler. Greatly improve the energy efficiency of the boiler. Saurabh Awti et al. (2017)studied about chimney plays very important role in the exhaust of flue gases from boiler to the atmosphere. It provides the first design of a heat recovery heat exchanger. In the design, an interchangeable core is completely made, but there is an incomplete air duct. This report is based on the work done and tested on the gas-to-gas heat recovery system. Especially the boiler chimney, so the piping system matches the entire boiler chimney. When completing the design, the main factor to be considered is the anti-fouling design. Therefore, the system is designed to reduce pollution, such as an easy-to-replace diesel particulate filter and a quick flush system. All machines within the system run unceasingly and consume heaps of energy Vinoth B et al. (2019).Vinoth B et al. (2019) say that correct management of the method system can result in energy savings, improved process potency, lower maintenance and operational costs, and exaggerated environmental safety. Several industrial heating processes generate waste energy. Reduces energy consumption one amongst the foremost effective ways in which to boost the efficiency of a boiler is to put in an economizer in the boiler. The essential plan is to extract the most quantity of warmth from the flue gases so as to heat the feed water of the boiler. Feed water can even be treated to cut back scale and sludge build-up, there by reducing boiler blowdown and fuel consumption. Chayalakshmi C.L et al. (2013) say that the boiler is a strength residence of any technique industry. The accumulation of soot and scale in the boiler is still the main problem to improve the performance of the boiler. Now a days, soot blowers can be operated manually in only one shift. Soot blower operation an automated method was developed, and the use of the ARM7 platform was applied in real time. The chimney temperature is used to control the airflow according to the standard. The built-in language C is used to provide the execution of automatic processing algorithms. The developed equipment is under research in the laboratory. Shiping Zhang et al. (2015) stated that monitoring the real-time pollution status of the ash stones produced by the boiler furnaces of power plants and the correct use of the boiler soot blowing system can greatly improve the safety and efficiency of such coal-fired boiler. This article examined the application of acoustic pyrometry near the water cooling wall by monitoring the temperature of the flue gases. SeungHeeEuh et al. (2016) studied on the effect of tar fouled on thermal efficiency of a wood pellet boiler. This study presents CFD (Computation Fluid Dynamics) simulation of thermal behavior of the boiler and analysis of the thermal efficiency affected by tar fouling on the heating surface of the combustion chamber. To investigate the effect of tar fouling on thermal efficiency, the experiments were performed by combusting the 1st and the 3rd grade wood pellets, and compared with the simulations. By about 1 mm tar fouling in heating surface of the boiler the thermal efficiency dropped by 7.26% and 9.19% in the 1st and the 3rd grade wood pellets, respectively. CaiYongtiea et al. (2017), Lv Tai (2012) and Yuanhao SHI (2015) studied on modeling of ash deposition in biomass boilers. The ash deposition method in biomass

boilers can generate a number of ash-associated problems. It will decrease the warmth move with inside the heater wall surfaces and convective by skip tubes and decrease the boiler overall performance and capacity. Previous evaluation work and revel in approximately the ash deposition method was nearly focusing on coal-fired electricity boiler, offering a vast recap of understanding and present tendencies approximately ash deposition processes, however couple of was focusing at the biomass fuel-derived boiler. Numeral empirical and conventional approaches, which include ash fusibility, ash thickness, and slagging and fouling indices, which are primarily based totally upon the temperature stage and chemical make-up, cannot absolutely assume the complex ash deposition method.

This research work is based on redesigning of the boiler chimney to reduce the fouling creation in furnace. In the redesigned chimney the flappers at various angles to increase the flue gas velocity in chimney convergent air duct are considered. The goal of the project work is to enhance the efficiency of boiler by reducing the fouling formed in heat transfer region. The 3D testing model of flue gas duct in chimney (new design) with flappers is prepared. The CFD analysis of flue gas duct in chimney was carried out to analyze the flue gas velocity changes in chimney. Fig. 2 shows the dimensions of the parts to be resigned. The calculation flappers at 3 different angles done.

2. BOILER SPECIFICATION

Table -1 : Boiler Specification

Boiler steam capacity	15 TPH
Working steam pressure	16 bar
Fuel	Coal
Fuel firing rate	2023 kg/hr
Steam generation rate	8954 kg/hr
Steam pressure	14 bar
Feed water temperature	90^{o}C
% Of co2 in flue gases	8%

% Of co in flue gases	1.6 %
Average flue gas temperature	210 °C
Ambient temperature	027 °C
Humidity in ambient air	0.018kj/kg of dry air
Surface temp of boiler	65 °C
Wind velocity around boiler	4 m/sec
Total surface area of boiler	118 mm²
G cv of bottom ash	700 K.cal/kg
G cv of fly ash	395 k.cal/kg
Ratio of b. A/ f.a	90;10
Ash content in fuel	7.80%
moisture in coal	29%
carbon content	38%

3. DESIGN CALCULATION

3.1 Data Required For Design Calculation

Table -2 : Data Required For Design Calculation

	Top diameter (in mm)	Bottom diameter (in mm)	Height (in mm)	Shell thickness (in mm)	Avg. diameter (in mm)
Seg 1	900	900	5000	6	900
Seg 2	900	900	5000	6	900
Seg 3	900	900	5000	6	900
Seg 4	900	900	5000	8	900
Seg 5	900	1575	5000	10	1237.5
Seg 6	1575	2250	5000	10	1912.5

3.2 Basic Dimension of Chimney

Total height of chimney = 30m

Height of flare = H = 1/3(30) = 10 m

Diameter of the flare =1.6x0.9 = 1.44m.

Computation of wind pressure:

The design wind speed at any height z is given by

$V_z = V_b.k_1.k_2.k_3$

Where,

Vb = basic wind speed at the site =37m/s for Pune.

k_1 = probability factor (risk coefficient) =1.0for general buildings and structures.

k_3 = topography factor =1.0 for flat topography

k_2 = terrain, height and structure size factor

$V_z = 37 \times 1 \times 1 \times k_2$.

Now design wind pressure,

$P_z = 0.6V2^2$

$= 0.6 \times (37 \times k_2)^2 \times 10^{-3}$ kN

$= 22.2\ k_2$ KN/m²

For chimney, adopting a shape factor of 0.7,

$f_z = (P_z.D.\Delta_z)\ 0.7$.

3.3 Calculation of wind speed pressure and force for each segment

Table -3 : Calculation of wind speed pressure and force for each segment

Segment	H(m)	k2	D (m)	Δ_z	P_z– 1.3245 k_2^2(kN/m²)	f_z– $(p_z.D.\Delta_z)$0.7(KN)
Seg 1	30	1.10	0.9	5	1.6037	5.0517
Seg 2	25	1.062	0.9	5	1.4962	4.1713
Seg 3	20	1.05	0.9	5	1.4612	4.6029
Seg 4	15	1.02	0.9	5	1.3789	4.3468
Seg 5	10	0.98	1.2375	5	1.2729	5.5132
Seg 6	5	0.98	1.9125	5	1.2729	8.5205

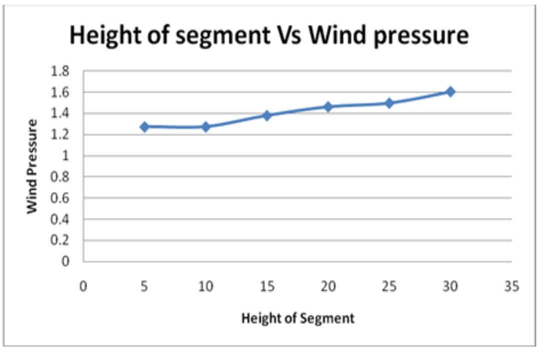

Chart -1: Graph showing change in wind pressure corresponding to Segment height

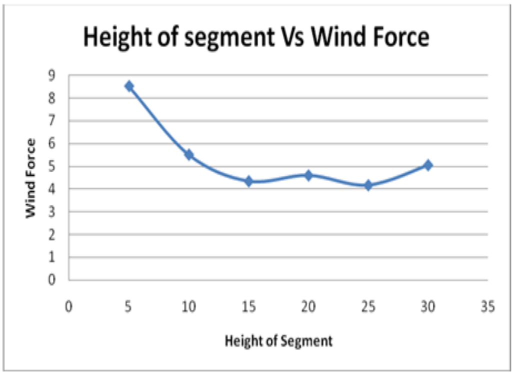

Chart -2 : Graph showing change in wind Force corresponding to Segment height

3.4 Moment at each section

Moment at segment s1=(5.0517 x 2.5)

=12.6292 KN-m

Moment at segment 2=(5.0517 x 7.5)+(4.1731x2.5)

=49.6705 KN-m

Moment at segment 3=(5.0517 x 12.5)+(4.1731x7.5)+(4.6029x2.5)

=110.0017 KN-m

Moment at segment 4=(5.0517 x 17.5)+(4.1731x12.5)+(4.6029x7.5)+(4.3436x2.5)

=192.6992 KN-m

Moment at segment 5=(5.0517 x 22.5)+(4.1731x17.5)+(4.6029x12.5)+(4.3436x7.5)+(5.5132x2.5)

=300.0387 KN-m

Moment at segment 6=(5.0517 x 27.5)+(4.1731x22.5)+(4.6029x17.5)+(4.3436x12.5)+(5.5132x7.5)+(8.5205x2.5) = 442.4625 KN-m

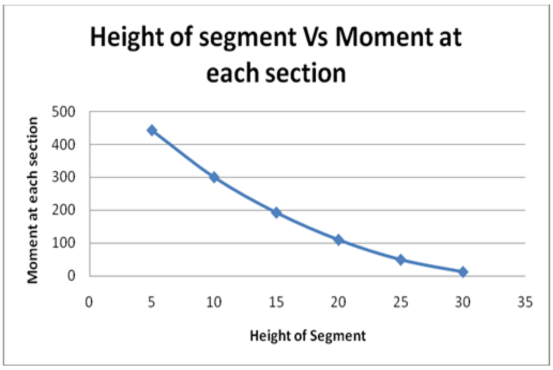

Chart -3 : Graph showing Moment at each section corresponding to Segment height

3.5 Design of Chimney Shell

Stress due to chimney weight,

fs=0.0785h N/mm^2

Stress due to weight of lining,

fl=0.002h/t N/mm^2

Stress due to wind,

fw=(0.004Mwxx)/(πD^2 t) N/mm^2

Minimum thickness of shell from stability point of view=D/500

=900/500 =1.8 mm.

It is assumed that the design life of steel chimney shell will be 20 years and coal is used for boiler. Hence add additional 4mm

Thickness to account for corrosion, Hence total minimum thickness of plate=6+4=10mm.

Effective thickness =10-4=6mm

fc = the maximum compressive force per unit length

ft = Maximum uplift force per unit length of circumference

3.6 Determination of stress

Table -4 : Determination of Stresses

Seg	h(m)	D(m)	T(mm)	D/t(mm)	h/D	fc (N/mm^2)	ft (N/mm^2)
1	5	0.9	6	150	5.55	124	105
2	10	0.9	6	150	11.11	124	105
3	15	0.9	6	150	16.66	124	105
4	20	0.9	8	112.5	22.22	108	105
5	25	1.2375	10	123.75	20.20	108	105
6	30	1.9125	10	191.25	25.1572	97	105

Stress due to chimney weight (fs)	Stress due to weight of lining (fl)	Stress due to wind (fw)	Fc max	Ft max	Stability check
0.3925	1.666	3.308	5.366	2.9155	stable
0.785	3.333	13.102	17.130	12.227	stable
1.1775	5	28.818	34.996	27.641	stable
1.57	5	37.86	44.43	36.29	stable
1.9625	5	24.94	31.908	22.977	stable
2.355	6	15.4022	23.757	13.047	stable

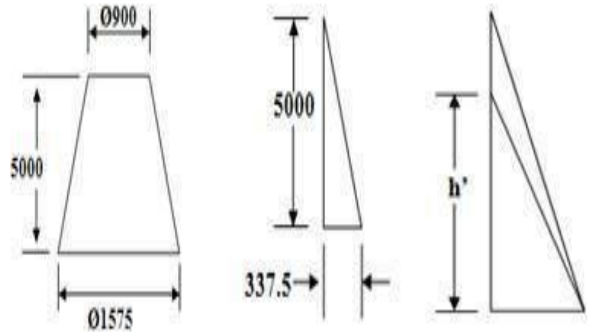

Fig -2 : Dimension of Part to be Re-designed

tan(α) = 5000/337.5 = 86.138°

Now adding the flappers at 3 different angles at 10^0, 12^0, 15^0

a) at 10 °

(β) = 86.138 ° - 10 °

= 76.138 °

tan(β) = h'/337.5

h' = 1367.70 mm

b) at 12 °

(β') = 86.138 ° - 12 °

= 74.138 °

tan(β) = h'/337.5

h' = 1187.79 mm

c) at 15 °

(β') = 86.138 ° - 15 °

= 71.138 °

tan(β) = h'/337.5

h' = 987.89 mm

4. CAD MODELLING

The CAD model was prepared by using CATIA V5 software. The V section is of 5000 mm high with outer diameter of 900 mm and base diameter of 1575 mm. The CAD model is shown in Fig. 3.

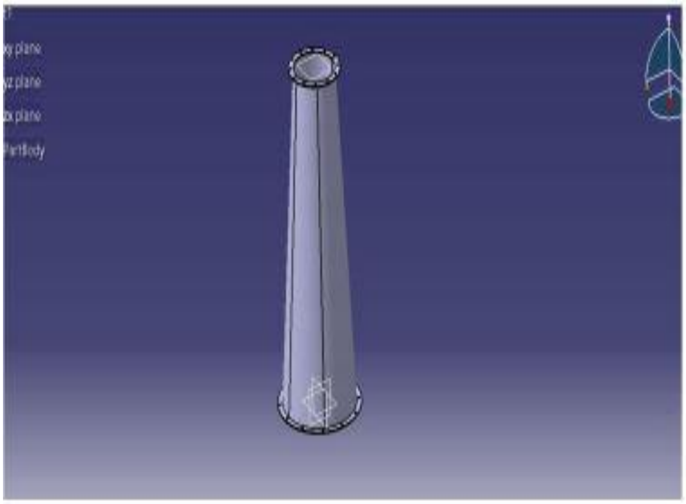

Fig -3 : CAD Model of segment

The structure or component is composed of an infinite number of particles or points, so they must be broken down into a limited number of parts. The grid is dividing a component by a finite number. The division of components helps us to calculate the power supply. A component composed of nodes and elements. The number of nodes and elements are formed accordingly. The meshed model is shown in Fig. 4.

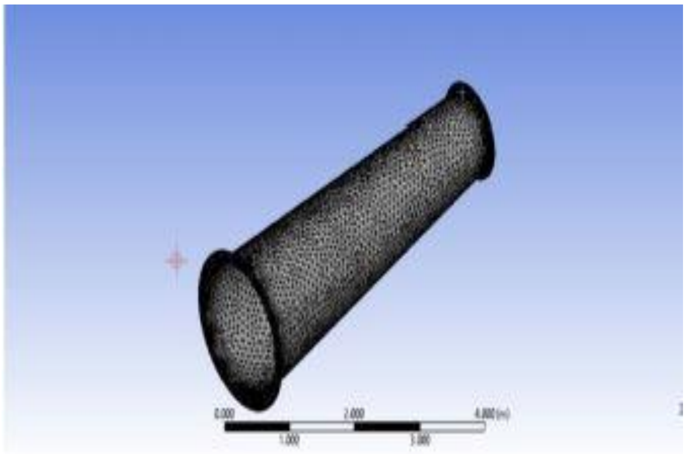

Fig -4 : Meshed model of segment

In redesigned project, CAD model of flapper inserted in chimney at different angle ranging from 10^0, 12^0 and 15^0 and get better performance. Figures 5, 6 and 7 shows the chimney with flappers at 10^0, $12^0$and 15^0 respectively.

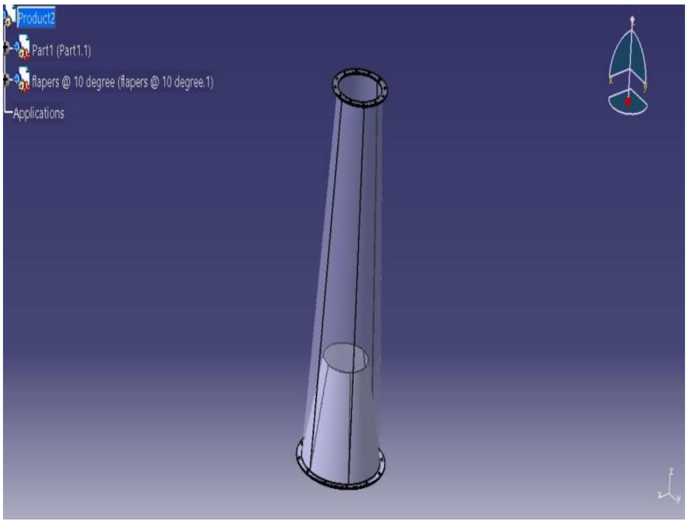

Fig -5 : Chimney segment with flapper at 10^0

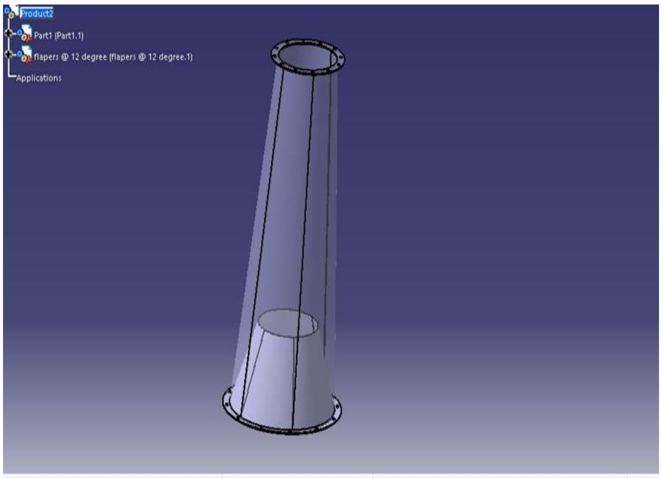

Fig -6 : Chimney segment with flapper at 12^0

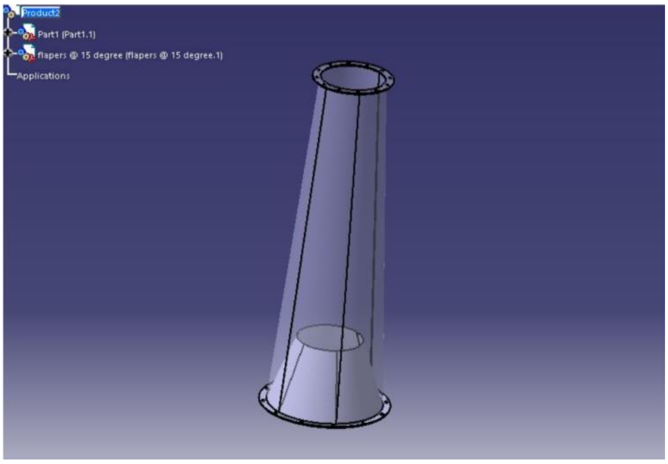

Fig -7 : Chimney segment with flapper at 15^0

5. CFD ANALYSIS

The CFD analysis is carried out using academic licensed ANSYS Fluent software. Based on literature the turbulent model is selected as k-epsilon turbulent model Khan et al. (2019), Pathan et al. (2017a,b,c; 2018a,b; 2019a,b,c,d; 2020a,b), Shaikh et al. (2020a,b).

The Fig. 8 shows the CFD analysis without flappers. The red color indicates the area of maximum velocity 8.147 ms^{-1} whereas the blue color indicates minimum velocity.

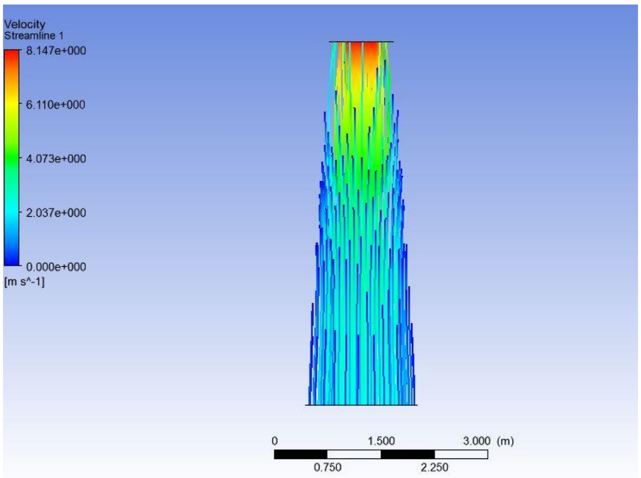

Fig -8 : CFD Analysis without flappers

The Fig. 9 shows the CFD analysis with 10^0 flappers. The red color indicates the area of maximum velocity 15.69 ms^{-1} whereas the blue color indicates minimum velocity.

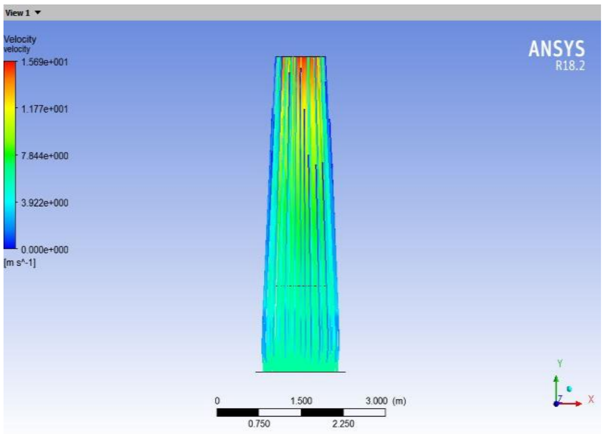

Fig -9 : CFD analysis with flapper at 10^0

The Fig. 10 shows the CFD analysis with 12^0flappers. The red color indicates the area of maximum velocity 15.78ms^{-1} whereas the blue color indicates minimum velocity.

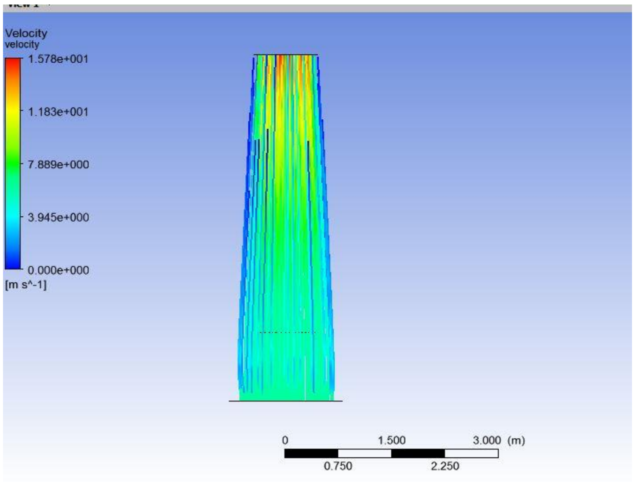

Fig -10 : CFD analysis with flapper at 12^0

The Fig. 11 shows the CFD analysis with 15^0 flappers. The red color indicates the area of maximum velocity 15.79ms^{-1} whereas the blue color indicates minimum velocity.

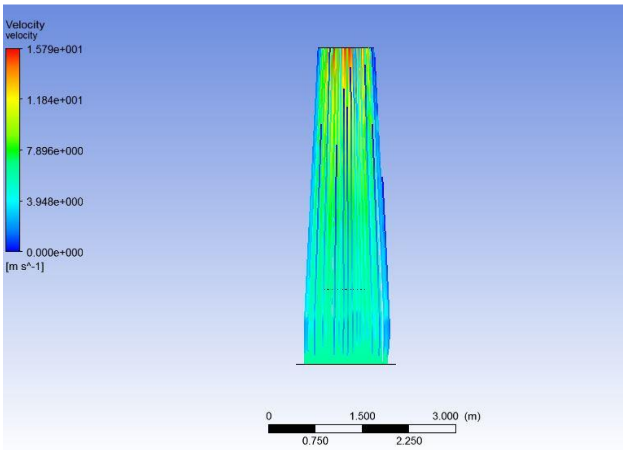

Fig -11 : CFD analysis with flapper at 15^0

6. RESULTS AND DISCUSSION

It can see that there is slightly increase in velocity of flue gases if flapper installed. As velocity is inversely proportional to pressure, the increase in velocity will cause the pressure drop in chimney. Due to increase in velocity, the hot flue gases does not come in contact with the chimney for much long time and decreases the rate of fouling. With this, the efficiency of the boiler can be increased, the maintenance required in redesigned boiler is less as compared to other boilers. With this modification the maintenance for the flapper will increase the overall maintenance cost.

Table -5 : Result Without Flapper

Steam Generation Rate	8950 Kg/Hr
Steam Pressure	14 Bar
Feed Water Temperature	90 oC
% Of Co2 In Flue Gases	8%
% Of Co In Flue Gases	1.6%
Average Flue Gas Temperature	115 oC
Ambient Temperature	27 oC
Surface Temp Of Boiler	65 oC
Wind Velocity Around Boiler	4m/Sec
Total Surface Area Of Boiler	118mm
Fuel Analysis In %	
Ash Content In Fuel	7.80%
Carbon Content	38%
Nitrogen Content	1.90%
Oxygen Content	5%
CV Of Coal	3450 To 3580 Kcal/Kg
Flue Gas Temp	315 oC
Thermal Efficiency	92.95%
Ash Fusion Temp	1100 oC
Fuel Consumption	2014 Kg/Hr
Steam Temperature	320 oC
Boiler Efficiency	46.2%

Table -6 : Result With Flapper

Steam Generation Rate	9030 Kg/Hr
Steam Pressure	13 Bar
Feed Water Temperature	90 oC
% Of Co2 In Flue Gases	8%
% Of Co In Flue Gases	1.6%
Average Flue Gas Temperature	130 oC
Ambient Temperature	27 oC
Surface Temp Of Boiler	65 oC
Wind Velocity Around Boiler	4 M/Sec
Total Surface Area Of Boiler	118 Mm
Fuel Analysis In %	
Ash Content In Fuel	7.80%
Carbon Content	38%
Nitrogen Content	1.90%
Oxygen Content	5%
CV Of Coal	3450 To 3580 Kcal/Kg
Flue Gas Temp	215 oC
Thermal Efficiency	92.95%
Ash Fusion Temp	1100 oC
Fuel Consumption	2014 Kg/Hr
Steam Temperature	320 oC
Boiler Efficiency	49.7%

Steam generation without flapper = 8950 kg/hr Fuel consumption= 2014 kg/hr

Steam generation with flapper = 9030 kg/hr Fuel consumption= 2014kg/hr

Percentage increase in the Boiler Efficiency:-(Output / Input)*100 = (80/2014)*100= 0.0397*100 = 3.94%

7. CONCLUSION

In this research work the attempts were made to reduce fouling by introducing flappers in the fifth section of the chimney. Flappers were installed at various angles like 10^0, 12^0 and 15^0 and CFD analysis is done on the results by comparing all of them. Analysis results showed that, the flappers installed helps increase the velocity of flue gases and hence reduce the soot formation i.e., fouling which eventually increases the efficiency of the chimney and also the life of chimney.

REFERENCES

[1] Mostafa M. Awad, (2011), "Fouling of Heat Transfer Surfaces", DOI: 10.5772/13696

[2] MoniKuntal Bora and S. Nakkeeran, (2014), "Performance Analysis of the Efficiency Es-timation of coal fired boiler",International Journal of Advance research, Volume-2,Issue-5, Page No:- (561-574).

[3] Rahul Deva Gupta, SudhirGhai, Ajji Jain, (2011) "Energy efficiency Instrument Strategies ForIndusrtial Boilers", Journal of Engineering and Technology, Volume-1, Issue-1, Page No:-(52-56), DOI: 10.4103/0976-8580.74541

[4] SaurabhAwti, AkshayPatil, VaibhavNarawade, SujitAgare, (2017), "Redesigning of a Boiler

Chimney System to Enhance Boiler Efficiency Against Fouling",International Journal of General Science and Engineering Research, Volume-1, page no. (1-2).

[5] Vinoth B, Ajo Thomas S J, Balamurugan G, Muthukrishnan M, Nagapandi P., (2019), "Reduction In Fuel Consumption Using Waste Heat Recovery And Blowdown Control System", International Journal of Mechanical Engineering.

[6] Chayalakshmi C.L, D.S. Jangamshetti, SavitaSonoli,(2013) "Design and Development of an ARM platform based Embedded System for Measurement of Boiler Efficiency" DOI:10.1109/ISIEA.2013.6738964

[7] ShipingZhangn, GuoqingShen, LiansuoAn, YuguangNiu, Genshan Jiang, (2015),"Monitoring ash fouling in power station boiler furnaces using acoustic pyrometry" ELSEVIER.

[8] CaiYongtieab, Yang Wenminga b., ZhengZhimina,b, XuMingchena b., SiahKeng Boon, (2017), "Modelling of ash deposition in biomass boilers", ELSEVIER.

[9] Yuan hao SHI, Jing chengWang(2015) "Ash Fouling Monitoring and key Variables Analysis For Coal Fired power Plant Boiler",Thermal Science 2015 Volume- 19,Issue- 1, Page No.(253-265), DOI: 10.2298/TSCI120428118S

[10] Khan Sher Afghan, M. A. Fatepurwala, K. N. Pathan, P. S. Dabeer, Maughal Ahmed Ali Baig (2019). CFD Analysis of Human Powered Submarine to Minimize Drag. International Journal of Mechanical and Production Engineering Research and Development 8(3) 1057-1066.

[11] Pathan Khizar Ahmed, S. A. Khan, and P. S. Dabeer (2017a). CFD analysis of the effect of flow and geometry parameters on thrust force created by flow from nozzle. 2nd International Conference for Convergence in Technology (I2CT), 1121-1125.

[12] Pathan Khizar Ahmed, S. A. Khan, and P. S. Dabeer (2017b). CFD analysis of the effect of area ratio on suddenly expanded flows. 2nd International Conference for Convergence in Technology (I2CT), 1192-1198.

[13] Pathan Khizar Ahmed, P. S. Dabeer, and S. A. Khan (2017c). CFD analysis of the effect of Mach number, area ratio, and nozzle pressure ratio on velocity for suddenly expanded flows. 2nd International Conference for Convergence in Technology (I2CT), 1104-1110.

[14] Pathan Khizar Ahmed, S. A. Khan, and P. S. Dabeer (2018a). An Investigation to Control Base Pressure in Suddenly Expanded Flows. International Review of Aerospace Engineering (I.RE.AS.E) 11(4), 162-169.

[15] Pathan Khizar Ahmed, P.S. Dabeer, Sher Afghan Khan (2018b). Optimization of area ratio and thrust in suddenly expanded flow at supersonic Mach numbers. Case Studies in Thermal Engineering 12, 696-700.

[16] Pathan Khizar Ahmed, P. S. Dabeer, and Sher Afghan Khan (2019a). Influence of Expansion Level on Base Pressure and Reattachment Length. CFD Letters 11(5), 22-36.

[17] Pathan Khizar Ahmed, Prakash S. Dabeer, and S. A. Khan (2019b), Investigation of Base Pressure Variations in Internal and External Suddenly Expanded Flows using CFD analysis. CFD Letters 11(4), 32-40.

[18] Pathan Khizar Ahmed, Prakash S. Dabeer, and S. A. Khan (2019c). Effect of Nozzle Pressure Ratio and Control Jets Location to Control Base Pressure in Suddenly Expanded Flows. Journal of Applied Fluid Mechanics 12(4), 1127-1135.

[19] Pathan Khizar Ahmed, Syed Ashfaq, Prakash S. Dabeer, and S. A. Khan (2019d). Analysis of Parameters Affecting Thrust and Base Pressure in Suddenly Expanded Flow from Nozzle. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 64(1), 1-18.

[20] Pathan Khizar Ahmed, Prakash S. Dabeer, and S. A. Khan (2020). An Investigation of Effect of Control Jets Location and Blowing Pressure Ratio to Control Base Pressure in Suddenly Expanded Flows. Journal of Thermal Engineering 6(11), 15-23.

[21] Pathan Khizar Ahmed, Prakash S. Dabeer, and S. A. Khan (2020). Enlarge duct length optimization for suddenly expanded flows. Advances in Aircraft and Spacecraft Science 7(3), 203-214.

[22] Shaikh, S.K., Pathan, K.A., Chaudhary, Z.I., Marlpalle, B.G., Khan, S.A (2020a), "An investigation of three-way catalytic converter for various inlet cone angles using CFD", CFD Letters**12** (9), 76-90. https://doi.org/10.37934/cfdl.12.9.7690.

[23] Shaikh, S.K., Pathan, K.A., Chaudhary, Z.I., Khan, S.A (2020b), "CFD analysis of an automobile catalytic converter to obtain flow uniformity and to minimize pressure drop across the monolith", CFD Letters**12** (9), 116-128. https://doi.org/10.37934/cfdl.12.9.116128.